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REVIEW PAPER

Historical evolution of magnetic data storage devices and related conferences

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Abstract

Telegraphic invention by Danish engineer Valdemar Poulson in 1898 was the first demonstration that a magnetic recording medium could be used to record information and for playback. It was not until 1947, that 3 M shipped the first commercial oxide tape coated on paper backing, and in 1953, IBM shipped the first magnetic tape drive, IBM 727, for data storage. IBM invented the first hard disk drive, IBM 305, called the random access method of accounting and control (RAMAC) for data storage. The RAMAC stored 5 MB of data and used fifty 24-in. diameter disks. The drive could be housed in a room of about 9 m $\times$ 15 m. It weighed over a ton and had to be moved around by forklifts. The cost was USD $250,000 at the time (a whopping $50,000 per MB!). In 2018, one could buy a 30 TB tape cartridge or 1 TB portable hard disk drives (with a 2.5-in. diameter disk), for about USD $100. Since the late 1970s, the tribology of head-medium interface has been considered a limiting technology for development of reliable drives with ever increasing recording densities. Given the importance of tribology, a first ever symposium on Tribology and Mechanics of Magnetic Storage Systems was held in 1984 at the ASME/STLE Tribology Conference, co-organized by B. Bhushan, D. Bogy, N. Eiss and F. Talke, and annually thereafter by Bhushan and Eiss. Many electromechanical, materials science, design and manufacturing issues also became important. In order to broaden the scope to include mechanical issues, the first International Symposium on Advances in Information Storage Systems was organized at the ASME Winter Annual Meeting in 1989 by B. Bhushan, and annually thereafter. B. Bhushan led the founding of Information Storage and Processing Systems (ISPS) Sub-division in ASME in 1992 which was elevated to a Division level in 1996. In 1993, the conference was renamed as the Annual Conference on ISPS. In 2018, the 27th Annual Conference on ISPS was held after 30th year of its inception, and the ISPS division celebrated its silver jubilee in 2017. The research papers continue to be published in a dedicated journal. This paper provides an overview of historical evolution of magnetic data storage devices and related conferences and publications with a focus on tribology and electromechanical, materials science, design and manufacturing issues.

Based on a distinguished banquet lecture given at the 27th ASME Annual Conference on Information Storage and Processing Systems and Micromechatronics for Information and Precision Equipment (ISPS/MIPE), San Francisco, CA on August 29, 2018.

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1 Introduction

Author will start by stating that whenever a major invention is made, one normally does not see a commercial value. Table 1 presents notable technology forecasts made at the time of inventions, which were so wrong(!) and are humorous. More recently, introduction of iPhone in June 2007 was not taken seriously either. Steve Jobs, CEO of Apple, changed the dynamics of technology forecasts. He stated in 1985 that “Customers don’t know what they want”. At Macworld 2006, he stated that “You can’t just ask customers what they want and then try to give that to them”. He further stated that customers don’t need, but they want his products.

The telegraphic invention by Danish engineer Valdemar Poulson in 1898 was the first demonstration that a magnetic recording medium could be used to record information and for playback. It was not until 1947, that 3 M shipped the first commercial oxide tape coated on paper backing, and in 1953, IBM shipped the first magnetic tape drive, IBM 727, for data storage. In 1957, IBM invented the first hard disk drive (rigid disk drive), IBM 305, called the Random Access Method of Accounting and Control (RAMAC) for data storage. The RAMAC stored 5 MB of data and used fifty 24-in. diameter disks. The drive could be housed in a room of about 9 m × 15 m. It weighed over a ton and had to be moved around by forklifts. The cost was USD $250,000 at the time (a whopping $50,000 per MB!). In 2018, one could buy a 30 TB tape cartridge or a 1 TB portable hard disk drive (HDD) (with 3 ½ in.-diameter disks) for about USD $100.

The magnetic recording process is accomplished by relative motion between a magnetic medium (tape or disk) against a read/write magnetic head (Bhushan 1996a, 1998a, 2000, 2001, 2017). The reproduced or playback signal amplitude [e(t)] in sinusoidal recording is directly proportional to separation loss. The separation loss is equal to an inverse exponential of the head-medium spacing (d) divided by recorded wavelength (λ) (Wallace 1951). Therefore, reproduced signal amplitude is related to head-medium spacing as

$$e(t) \propto \exp(-2\pi d/\lambda) \quad (1)$$

For high reproduced signal amplitude, the magnetic medium needs to be in close proximity to the magnetic head. However, close proximity results in tribological issues.

To minimize tribological issues, under steady operating conditions, the head surface is designed to develop a load carrying air film by hydrodynamic effects at the interface in order to maintain physical separation between the head

Table 1 Notable technology forecasts at the time of inventions

Name (year)	Quote
(a) These were so wrong(!) and are humorous	
Thomas Edison (1880)	The phonograph…is not of commercial value
Robert Millikan, Nobel Prize Winner, Physics (1920)	There is no likelihood man can ever tap into the power of the atom
Harry Warner, Warner Brothers’ Pictures (1927)	Who the hell wants to hear actors talk?
Thomas J. Watson, Chairman of IBM (1943)	I think there is a world market for about five computers
Ken Olsen, President of Digital Equipment Corp. (1977)	There is no reason for an individual to have a computer in their home
(b) Apple changed the dynamics of technology forecasts	
Steve Ballmer, CEO of Microsoft (June 2007)	Apple will have the most expensive phone, by far, in the marketplace. There is no chance that the iPhone is going to get any significant market share. No chance. (The original iPhone ended up selling over 6 million units in its first year!)
Steve Jobs, CEO of Apple (2006)	He changed the dynamics of technology forecast. In 2006, he stated that “You can’t just ask customers what they want and try to give that to them”. He further stated that customers don’t need, but they want (his products)

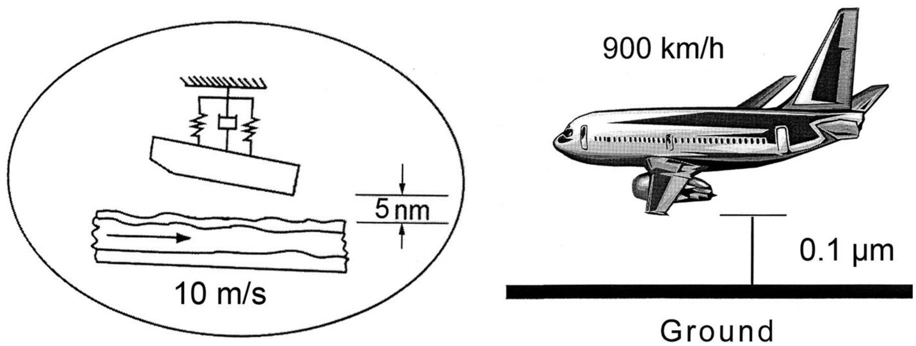


Fig. 1 A magnetic head slider flying over a disk surface compared with an aircraft flying over ground with a close physical spacing

surfaces and medium surfaces. However, there is a physical contact between the medium and the head surfaces when starting and stopping, and tribology of head-medium interface remains important (Bhushan 1996a, 1998a, 2000, 2001, 2017). In modern hard disk drives, the head slider and disk surfaces are coated with ultrathin (couple of nm thick) of diamondlike carbon (DLC) films for corrosion and wear protection and have surface roughness of a couple of nm rms. The head-to-medium separation is on the order of 1–3 nm. As an analogy, a magnetic head slider flying over a hard disk surface with a flying height of 5 nm and a relative speed of 10 m/s is equivalent to an aircraft flying at a physical spacing on the order of 0.1 μm at 900 km/h (Fig. 1). In this scenario, the aircraft would crash in no time. This is what a head-disk interface experiences during its operation over the lifetime.

The hard disk drives sold in 2018 had a lifetime of more than 5 years. They had an annualized failure rate (AFR) (a measure of the estimated probability that the drive will fail during a full year in use) of less than 0.5% and a mean time before failure (MTBF) of more than 2 million hours, based on hard disk drive specs from Seagate Technology and Western Digital Corporation.

Since the late 1970s, the tribology of head-medium interface has been considered a limiting technology for development of reliable drives with ever increasing recording densities. Given the importance of tribology, a first ever Symposium on Tribology and Mechanics of Magnetic Storage Systems was held in 1984 at the ASME/STLE Tribology Conference, co-organized by B. Bhushan, D. Bogy, N. Eiss and F. Talke, and annually thereafter by Bhushan and Eiss. Many electromechanical, materials science, design and manufacturing issues also became important. In order to broaden the scope to include mechanical issues, the first International Symposium on Advances in Information Storage Systems (AISS) was organized at the ASME Winter Annual Meeting in Nov. 1989 by B. Bhushan, and annually thereafter. In 1999, it moved to Santa Clara, CA and later to San Francisco, CA. B. Bhushan led the founding of Information Storage and Processing Systems (ISPS) Sub-division in ASME in 1992 which was elevated to a Division level in 1996. In 1993, the conference was renamed as the ASME Annual Conference on ISPS. In 2018, the 27th ASME Annual Conference on ISPS was held after 30th years of its inception, and the ISPS division celebrated its silver jubilee in 2017. The research papers continue to be published in a dedicated journal.

This paper provides an overview based on a distinguished banquet lecture given at the 27th Annual Conference on ISPS, on the historical evolution of magnetic data storage devices and related conferences. It starts with the first demonstration of magnetic recording followed by the historical evolution of magnetic storage devices which include tape drives, rigid disk drives and flexible (floppy) disk drives, and then storage hierarchy and future outlook for magnetic storage. Then, a historical evolution of related magnetic storage conferences and publications is presented, followed by closing remarks.

2 First demonstration of magnetic recording

The telegraphone invention in 1898 by a Danish engineer, Valdemar Poulsen of the Copenhagen Telephone Company in Copenhagen was the first demonstration that a magnetic medium could be used to record information and for playback. In his demonstration, Poulsen used a strung-out steel piano wire, shown in Fig. 2 (Camras 1988). On a trolley carriage, he hung an electromagnet connected to a battery and a telephone transmitter (microphone) to record. He moved the electromagnet along the wire as he spoke into the microphone. Then he moved the carriage back to the top, disconnected the battery and transmitter, and now connected a telephone receiver across the electromagnet. He allowed the carriage to roll down the wire and could hear a faint reproduction of his voice in the earpiece. He then ran a strong magnet across the wire and was able to wipe out the recording. On the cleaned wire, he could record again. This clearly was the first demonstration that

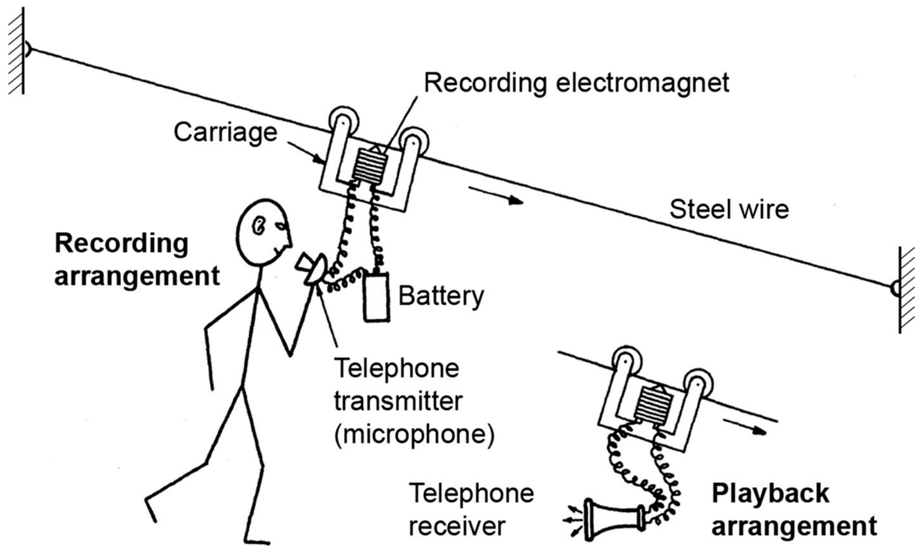


Fig. 2 Valdemar Poulsen demonstrated recording with a steel piano wire and electromagnet connected to a telephone transmitter (microphone) and demonstrated playback by connecting the electromagnet to the telephone receiver

magnetic recording/playback is possible. Figure 3 shows selected figures from his Danish Patent no. 2653.

The record that Poulsen made on his steel wire was nothing more than a multipolar magnet similar to the one shown in Fig. 4, but greatly reduced in diameter. When he spoke into the transmitter, he varied the electric current that the battery sent through the electromagnet. Thus he varied the magnetic field at the tip of the magnet where it touched the wire. Each point on the steel wire became permanently magnetized according to the strength of the electromagnet at the moment it travelled by. One might therefore consider the recording magnet as a stylus that wrote a magnetic pattern on the steel wire. The pattern corresponded to the condensation and rarefactions of the air waves that made up the original sound.

In playing back the record, the magnetic patterns of the wires set up a changing field in the electromagnet. This changing field induced a voltage in the magnet winding. The receiver connected to the magnet was operated by the voltage, and converted the fluctuating electric energy back into sound waves.

Poulsen called his invention the *telegraphone*, a combination of “telegraph” and “telephone”. He believed that one of its most important uses would be the recording of telephone messages, and the name telegraphone signified “writing down a distant voice”.

The telegraphone seemed especially useful for dictation purposes because the wire could be erased and used over again. A number of attempts were made in Europe and the USA. In 1908, C. K. Frankhauser, the president of the American Telegraphone Company reported further development of the telegraphone used for recording of spoken words. Later, the telegraphones were installed in offices for telephone recording, dictation, and train dispatching. However, the machine was heavy, expensive and difficult to operate.

3 Historical evolution of magnetic storage devices

Through the years, developments in magnetic recording took place. A chronology of the magnetic storage device development in early stages is presented in Table 2. Devices include tape drives, hard disk drives, and flexible (floppy) disk drives.

3.1 Tape drives for audio, video and data recording

In 1947, 3 M shipped the first **commercial** magnetic tapes coated on paper backing with γ-Fe_2O_3 magnetic particles (referred to as oxide tapes).

In 1948, Ampex shipped the first **commercial** audio tape recorder, Ampex 200A (Fig. 5a). This was a revolutionary change for the broadcast industry. The recorders used 14 in. open flanges, ¼-in. tape with oxide coating on acetate (3 M Scotch 111) and ran at 30 in/s. It sold for USD $5000. In 1951, 3 M demonstrated video recording followed by RCA in 1953.

In 1953, IBM shipped the first **commercial** magnetic tape drive, IBM 727, for data storage (Fig. 5b). It used a ½-in. wide and 2400 ft long oxide tape with a reel to reel format. The tape head had seven parallel tracks—six for data and one to maintain parity. The areal recording density was 1.4 kbits/in^2. The tape could be read in either direction at a rate of 75 in./s. One reel could store 2.3 MB of data. It could be rented for $500/month.

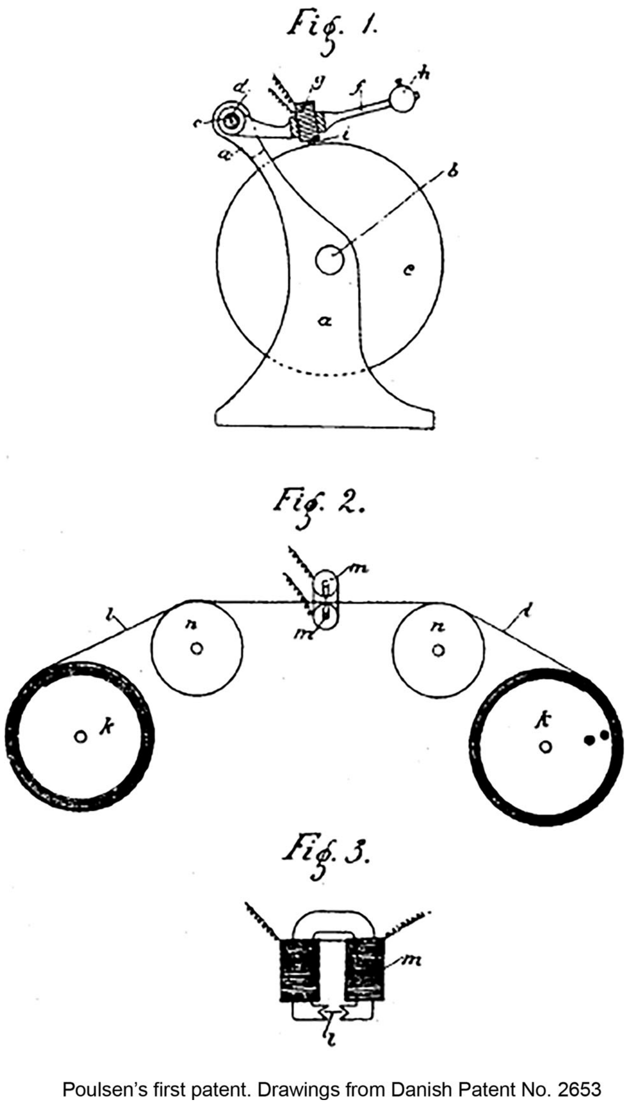


Fig. 3 Selected figures from Valdemar Poulsen's first Danish Patent no. 2653

Reel-to-reel data storage tape drives remained state-of-the-art until 1984 when IBM announced an IBM 3480 tape drive with a data cartridge containing a single reel with a storage capacity of 200 MB. The tape was ½-in. wide with chromium dioxide magnetic particles on polyethylene terephthalate (PET) substrate. It was packaged in a 4 in. × 5 in. × 1 in. cartridge. The size of the tape drive was also reduced. The data cartridge remains the standard format in 2018 with a storage capacity of 30 TB. A single robotic tape library could contain up to 278 petabyte of data. A 30 TB tape cartridge with normal compression for LTO-8 Ultrium tape drives could be bought for about USD $100. LTO stands for linear tape open, a digital tape format established by IBM, Seagate and HP.

In 1956, Ampex announced the first **commercial** rotating-head video tape recorder, Ampex VTR VR 1000

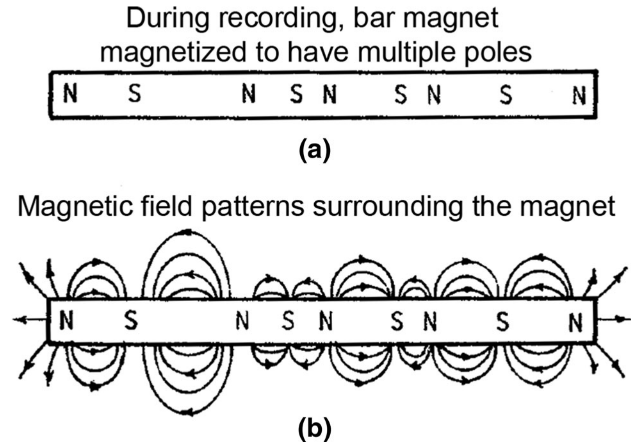


Fig. 4 During recording, **a** a bar magnet can be magnetized so as to have multiple poles, and **b** field patterns surrounding the multipole bar magnet

(Fig. 5c). The video recorder revolutionized the television broadcasting industry. It used a 4800-foot-long, 2 in. quadruplex video tape reel, also called 2 in. quad. The term quadruplex refers to the use of four magnetic read/write heads mounted on a head wheel spinning transversely across the tape (transverse format) at a rate of 14,400 rpm. The tape speed was15 in./s. It could store 1 h of recording. The cost was USD $45,000. In 1960, Ampex introduced helical scan recording. RCA soon followed with the help from Ampex. With the advancements in digital recording, in early 2000, analog audio and video recorders died.

3.2 Hard disk drives

IBM Research Division at San Jose, California invented a hard disk storage device with random access for data storage. In 1957, IBM shipped the first **commercial** hard disk drive (rigid disk drive), IBM 305, called. Figure 6 shows the photograph of the drive and artistic conception of the head-disk assembly. It used fifty, 24-in. diameter aluminum disks coated with γ-Fe_2O_3 magnetic particles and polymer binder. Two independent arms moved up and down to select a disk and in and out to select a recording track, all under servo control. The magnetic head sliders were supported on air film with a spacing of 25 μm developed using a hydrostatic bearing. Average time to locate a single record, referred to as access time was 600 ms. The drive stored 5 MB of data at an areal density of 2 kbits/in.^{2}. The drive could be housed in a room with a size of about 9 m × 15 m. It weighed over a ton and had to be moved with forklifts. It leased for $3200/month. The cost was USD $250,000, a whopping $50,000/MB!

The disk size has continued to decrease with doubling of areal density about every 18 months, referred to as Moore's law in semiconductor industry. The cost per MB of storage has also decreased by a factor of 2 every

Table 2 Chronology of magnetic storage devices development in early stages

Year	Magnetic storage devices development
(a) Tapes and tape drives for audio, video and data recording	
1920s	The first recorders with steel tapes made by Germans
1928	Fritz Pfleumer filed a patent for coating γ-iron oxide particles into a strip of paper as a recording medium
1935	German magnetophone exhibited in Berlin. Used a plastic base with a magnetic coating
1947	3 M shipped the first **commercial** oxide magnetic tapes coated on paper backing
1948	Ampex shipped the first **commercial** audio tape recorder (Ampex 200A)
1951	3 M demonstrated video recording. In 1953, RCA followed
1953	IBM shipped the first **commercial** magnetic tape drive for data storage (IBM 727)
1956	Ampex announced the first **commercial** rotating-head video recorder (Ampex VTR VR-1000). Used transverse format
1960	Ampex introduced helical scan recording to record a field continuously
(b) Hard disk drive for data storage with random access	
1957	IBM shipped the first **commercial** hard disk drive, called Random Access Method of Accounting and Control (RAMAC) (IBM 305)
(c) Flexible (floppy) disk drive for data storage (a cheaper alternative)	
1972	IBM shipped the first **commercial** flexible (floppy) disk drive using 8 in. flexible disk in a rectangular shell (IBM 23FD)

18 months. In 2018, the disk size included 2.5-in. and 3.5-in. diameters and the number of disks ranged from one to few. The recording areal density was several TB/in.^{2} with 1 TB portable disk storage having a single 2.5-in. diameter disk. It could be bought for about USD $100.

3.3 Flexible (or floppy) disk drives

In 1972, IBM shipped the first **commercial** flexible (or floppy) disk drive as a cheaper alternative, for data storage, IBM 23FD (Fig. 7a). It used an 8-in. flexible disk, also referred to as a floppy disk in a rectangular shell (Fig. 7b). It held 80 kB of data. The more conveniently sized 5¼ in. disks were introduced in 1976 followed by the 3½ in. format in 1982 (Fig. 7b). They were not used much in the early 2000s and production of 3½ in. floppy disks was stopped in 2011.

4 Storage hierarchy and future outlook for magnetic storage

4.1 Storage hierarchy

Tapes and hard disks play complimentary roles (near line and online) that utilize their unique features. Floppy disks, having a low capacity, were a cheaper alternative for offloading data. However, they stopped being in use after about 2011.

A comparison of nominal access times and prices in 2017 and 2020 (projected) for various technologies is presented in Table 3. Hard disk drives with their random access have access time on the order of few milliseconds, much shorter than tape drives. Hard disk drives are used for online data storage. They have high areal density of several TB/in^2.

Tapes have substantially more surface area on which to store data than any other medium. A data cartridge in 2018 had tape length of about 3000 ft. to store the data on. This causes tapes to have extremely high volumetric density (up to tens of gigabytes per cartridge) and high data rates. These are much cheaper than the hard disks in $/MB ($\sim$ $0.02/MB) but are not random access. The tape drives are primarily used for offloading the online data from hard disks for archival storage.

4.2 Future outlook for magnetic storage

Big data analytics and artificial intelligence have created strong demand for enterprise to amass information. Studies show that amount of data being recorded is increasing about 30–40% per year. There is also growing demand for storing data in the cloud, which is called cold storage. Based on some estimates, in 2017, about 3 exabytes (3 billion GB) of data was generated every day, the data at rest was about 2 ZB (2 trillion GB), and data in motion through global internet traffic was about 1 ZB (1 trillion GB) per year. It is estimated that 80–90% of data created never gets accessed again.

Based on some estimates, in 2017, there were some 2.5 billion hard disk drives in operation. There were some two hundred million LTO cartridges worldwide with 400 million TB of data being stored on them. Therefore, there were on the order of 10 times more HDD than tape cartridges making HDDs vastly more prevalent today.

Given a large data storage infrastructure, it requires significant energy consumption and energy efficiency is an important issue. For an equivalent amount of data, HDD uses on the order of 70 times more energy than a tape drive array. Thus, tape drives significantly reduce heating ventilation and air conditioning requirements.

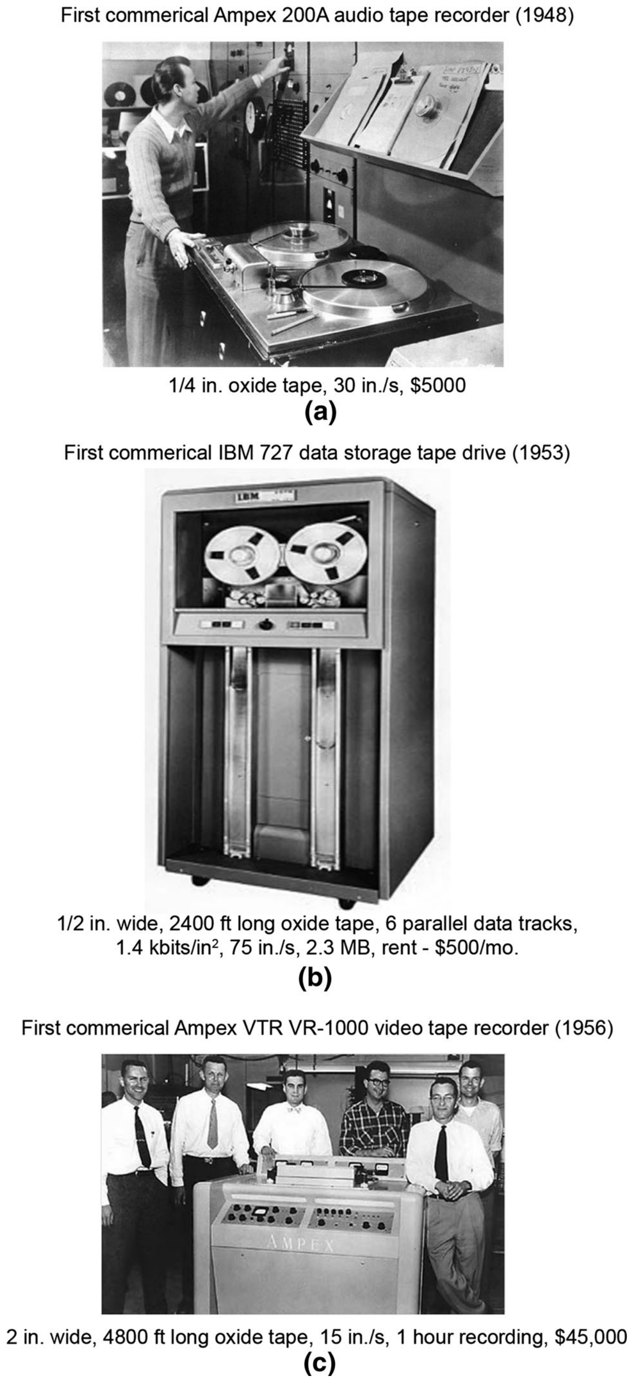


Fig. 5 Photographs of the first commercial **a** Ampex 200A audio tape recorder introduced in 1948; **b** IBM 727 data storage tape drive in 1953, and **c** Ampex VTR VR-100 video tape recorder in 1956

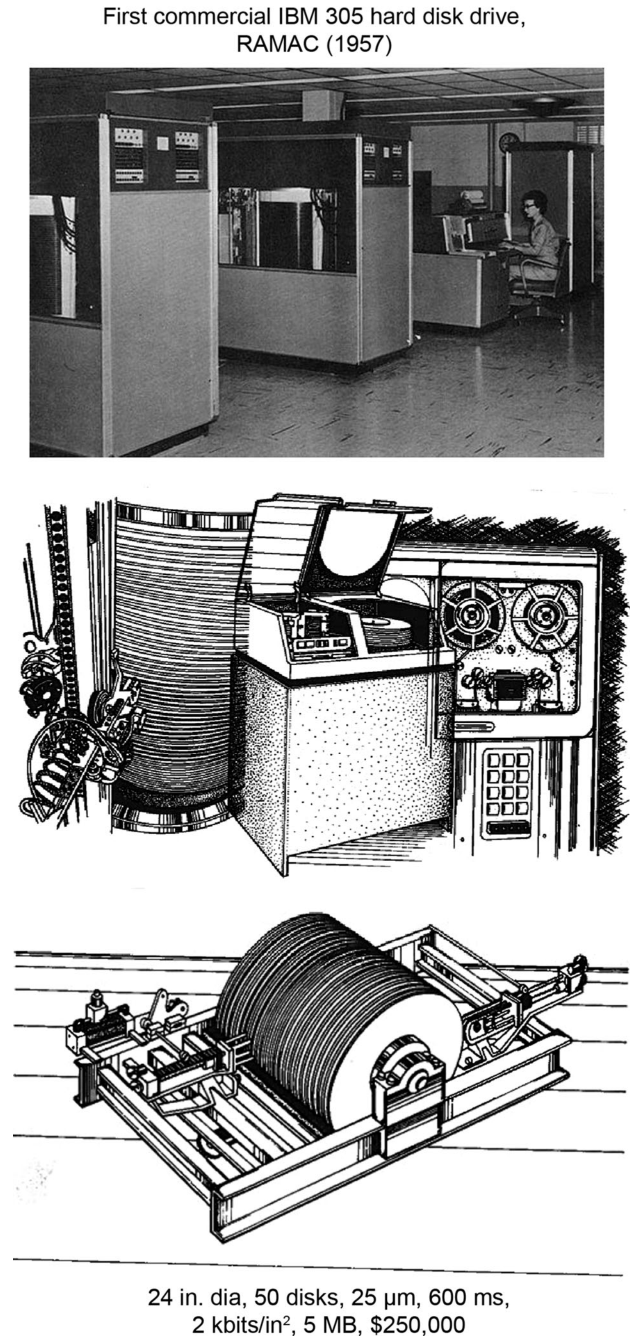


Fig. 6 Photograph of IBM 305 hard disk drive, RAMAC, and artistic conception of the head-disk assembly first commercially produced in 1957

Reliability of storage media is also critical requiring almost 100% data recovery with near zero failure rate. Both hard disk and tape drives are highly reliable. In the case of significant damage to data storage, tape drives may offer an advantage. For example, if the backup tapes are submerged under a few feet of water, the chances of a full data recovery are far better than those for any disk. The tapes in some cases can read on another tape drive. As an example, after unfortunate crash of the Challenger space shuttle in 1986, recorder tapes were immersed in seawater for 6 weeks before recovery. The damaged tapes could not be unwound without damaging the recording surface. After a chemical treatment, tapes could be unwound and copied onto another tape with great care and then read on a different drive (Bhushan and Phelan 1987).

First commercial IBM 23FD floppy disk drive (1972)

8-in. diameter disk, 80 kB

(a)

8-in., 5¼-in., and 3½-in. floppy disks

(b)

Fig. 7 Photographs of **a** 8-in. IBM 23FD data storage floppy disk drive (1972) and **b** 8 in., 5 ¼ in. and 3 ½ in. floppy disks

In early 2000, the hard disk drive annual revenue was on the order of \$50 billion/year. Worldwide unit shipment of HDD from 1976 to 2020 (projected) is presented in Fig. 8. A shipment of about 400 million units of HDD took place in 2017. Since 2010, the magnetic hard disk drive market has been shrinking and is approaching a limit in areal density. It is being replaced with solid state drives (SSD), flash memory storage, and other technologies. Solid state technologies do not have moving parts and are expected to be more reliable. Despite the SSD success story, HDD is not going away. HDD manufacturers continue to make capacity gains by increasing areal density and packing more heads and disks into single drives. SSDs remains more expensive than HDD, roughly 6 times in 2018 (Table 3).

Magnetic tape drives remain dominant for active archives and long term backup retention and archival. Much of worlds data is stored on tape. All Government and corporate records, telephone call records, and satellite data are archived. As an anecdote, in early 2000s, president of Imation Corporation stated that, after 9/11/2011, all corporate records from World Trade Center were recovered in 3 days after the tragedy. All data from offices located at the World Trade Center were backed up by 17 data centers located in New Jersey across the Hudson river.

In 2018, tape drives revenues were about USD \$3 billion annually. In 2017, IBM and Sony announced a major advancement in the development of magnetic tapes with sputtered multilayered magnetic coating. Sputtered coatings have been used in hard disk drives since 1980s. The sputtered film is thinner and has narrower grains, with magnetization that points up or down relative to the surface. This allows more bits in the same tape area. Projected areal density is astounding 201 GB/in.^{2}. A palm sized cartridge with a km long tape could store 330 TB of data. This capacity is higher than that of any competing technologies on the horizon!

To sum up, tape drives provide the highest volumetric density with lowest cost per MB and are energy efficient. Given that there is a need for ever increasing archival storage, tape drives will remain in use for another two decades, and will outlast HDD.

5 Historical evolution of related magnetic storage conferences and publications

5.1 Related magnetic storage conferences

A chronology of related magnetic storage conferences with a focus on tribology and electromechanical, materials science, design and manufacturing issues and formation of

Table 3 Comparison of access times and prices in 2017 and 2020 (projected) for various storage technologies (http://www.theregister.co.uk/2017)

Tier	Storage technology	2017 nominal access time	2020 nominal access time (projected)	2017 price in USD	2020 price in USD (projected)
Frequently accessed	SSD	10 µs	1 µs	\$250/TB	\$175/TB
Online	HDD	5 ms	5 ms	\$56/TB	\$38/TB
Near line	Tape library	120 s	90 s	\$21/TB	\$5.5/TB

SSD solid state drive, *HDD* hard disk drive

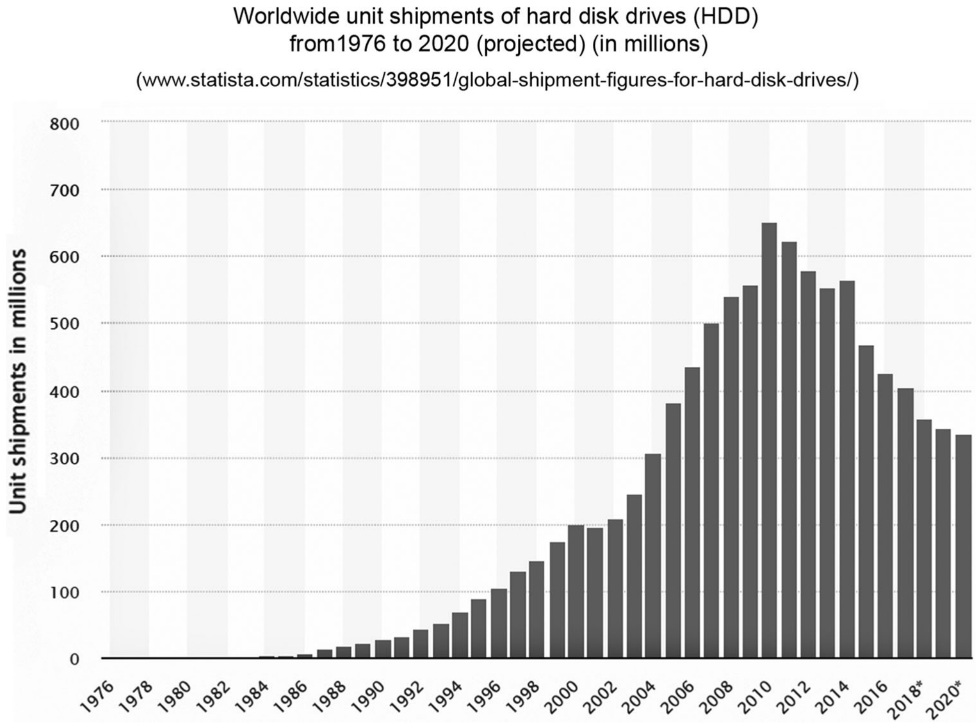


Fig. 8 Worldwide unit shipments (in millions) of hard disk drives (HDD) from 1976 to 2020 (projected)

Information Storage and Processing Systems (ISPS) division is presented in Table 4. Since the late 1970s, the tribology of head-medium interface has been considered a limiting technology for development of reliable drives with ever increasing recording densities. At that time, no topical meetings were held in these areas. Given the importance of tribology, a first ever symposium on Tribology and Mechanics of Magnetic Storage Systems was held in 1984 at the ASME/STLE Tribology Conference, co-organized by B. Bhushan, D. Bogy, N. Eiss and F. Talke, and annually thereafter, co-organized by Bhushan and Eiss. In 1984, at the first symposium, it tripled the attendance of the Tribology Conference with most people attending the magnetic storage sessions with standing room only.

Many electromechanical, materials science, design and manufacturing issues also became important. In order to broaden the scope to include mechanical issues, the first International Symposium on Advances in Information Storage Systems (AISS) was organized at the ASME Winter annual meeting (later called International Mechanical Engineering Congress and Expositions, IMECE) in Nov. 1989 by B. Bhushan and annually thereafter. ASME Annual Meeting was selected because most divisions participate at this meeting and the conference could attract participation from various divisions. Furthermore, the term “information storage” was used in the conference name to include both magnetic and non-magnetic storage systems. In 1993, conference name was changed to ASME Annual Conference on Information Storage and Processing Systems (ISPS). In 1999, it moved to bay area at Santa Clara, CA rather than at ASME IMECE to be held in Nashville, Tennessee that year. Later, it moved to San Francisco, CA. A photograph of some attendees at the international symposium on AISS in Nov. 1992 is shown in Fig. 9.

Table 4 Chronology of related magnetic storage conferences and formation of ISPS Division

Year	Related magnetic storage conferences and formation of ISPS Division
1984	Symposium on Tribology and Mechanics of Magnetic Storage Systems at ASME/STLE Tribology Conference
1989–1998	International Symposium on Advances in Information Storage Systems (AISS) at the ASME Winter Annual Meeting (later became International Mechanical Engineering Congress and Exposition, IMECE). In 1993, renamed as ASME Annual Conference on Information Storage and Processing Systems (ISPS)
1999	Moved to Santa Clara, CA in 1999, and later to San Francisco, CA
	ASME ISPS Division
1992	Founded ASME Information Storage and Process Systems (ISPS) Subdivision
1996	Elevated to permanent ISPS Division

Fig. 9 Photograph of some attendees at the AISS Symposium in Nov. 1992; seated in the front row on the right—B. Bhushan

Table 5 Chronology of related magnetic storage publications

Year	Publication
1984–1990	Special publications on Tribology and Mechanics of Magnetic Storage Systems
1991–1999	Advances in Information Storage Systems (AISS) Series
1999–2001	Journal of Information Storage Processing Systems (JISPS)
2002	Microsystem Technologies (MST)

Because of significant interest, in 1991, B. Bhushan and colleagues started a campaign to form a division. About 400 signatures (only 100 required) were collected on the petition from all over the world to support the formation of a division. ASME approved the formation of Information Storage and Processing Systems (ISPS) Sub-division in 1992. It was elevated to Division level in 1996. From 1993 to 1996, its primary membership grew to over 300. B. Bhushan served as its founding chair, 1992–1998.

In 2018, the 27th ASME Annual Conference on ISPS was held in San Francisco, CA, after 30th year of its inception and the ISPS division celebrated its silver jubilee in 2017.

5.2 Publications

A chronology of related magnetic storage publications is presented in Table 5. Referred papers presented at the Symposium on Tribology and Mechanics of Magnetic Storage Systems were published in special publications from 1984 to 1990 (Bhushan et al. 1984; Bhushan and Eiss 1985, 1986, 1987, 1988, 1989; Bhushan 1990). The title page and table of contents for the first proceeding are shown in Fig. 10a.

Referred papers presented at the International Symposium on AISS as well as contributed papers were published in an AISS series launched in 1991 (Bhushan 1991a, b, c 1992, 1993, 1995, 1996b, 1998b, c, 1999) as well in the proceedings (Adams et al. 1995, 1996, 1997, 1998). The title page and table of contents for the first issue of AISS are shown in Fig. 10b.

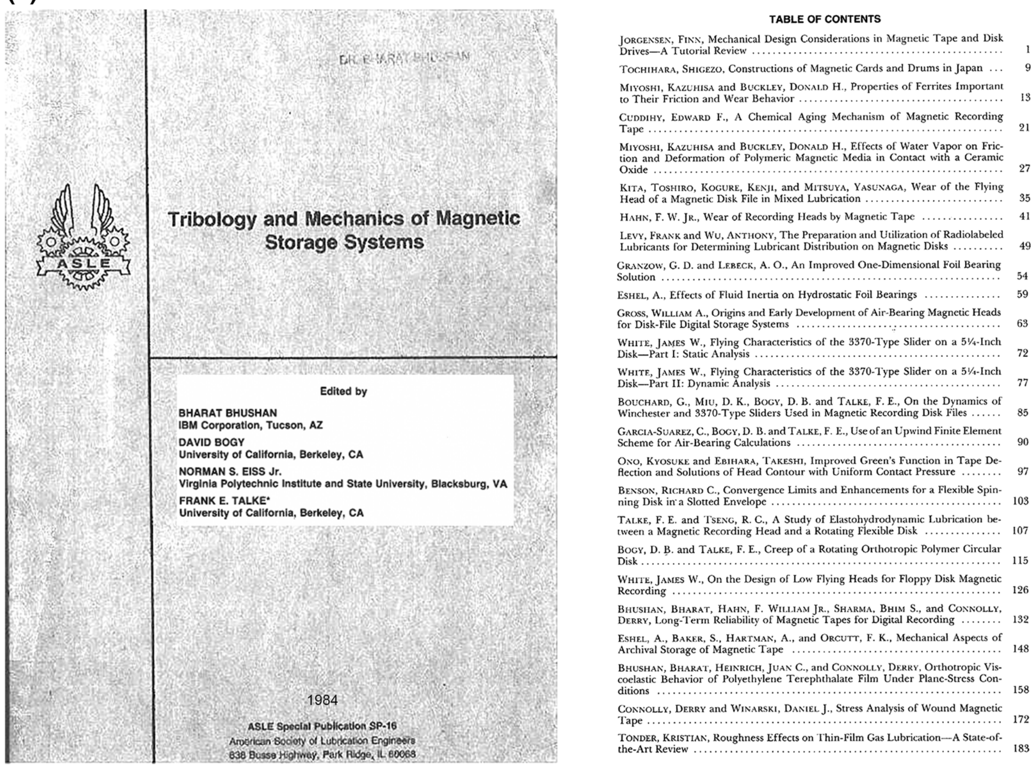
A new journal, titled as Journal of Information Storage and Processing Systems (JISPS) was launched in 1999 and was published until 2001. It contained referred papers from the ISPS conferences as well as contributed papers. The title page and table of contents for the first issue of JISPS are shown in Fig. 11a.

In 2002, scope of journal titled Microsystem Technologies (MST) was expanded to include the scope of ISPS. Referred papers for the ISPS conference as well as contributed papers have been published in MST since 2002. The title page and table of contents of the first issue after its expanded scope are shown in Fig. 11b.

6 Closing remarks

Magnetic storage devices have been used in audio, video and data recording applications, since 1948. For data processing, a first commercial magnetic tape drive was shipped in 1953 and a first commercial magnetic hard disk drive was shipped in 1957. With the advance of digital

(a)


Tribology and Mechanics of Magnetic Storage Systems

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ASLE Special Publication SP-16
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(b)

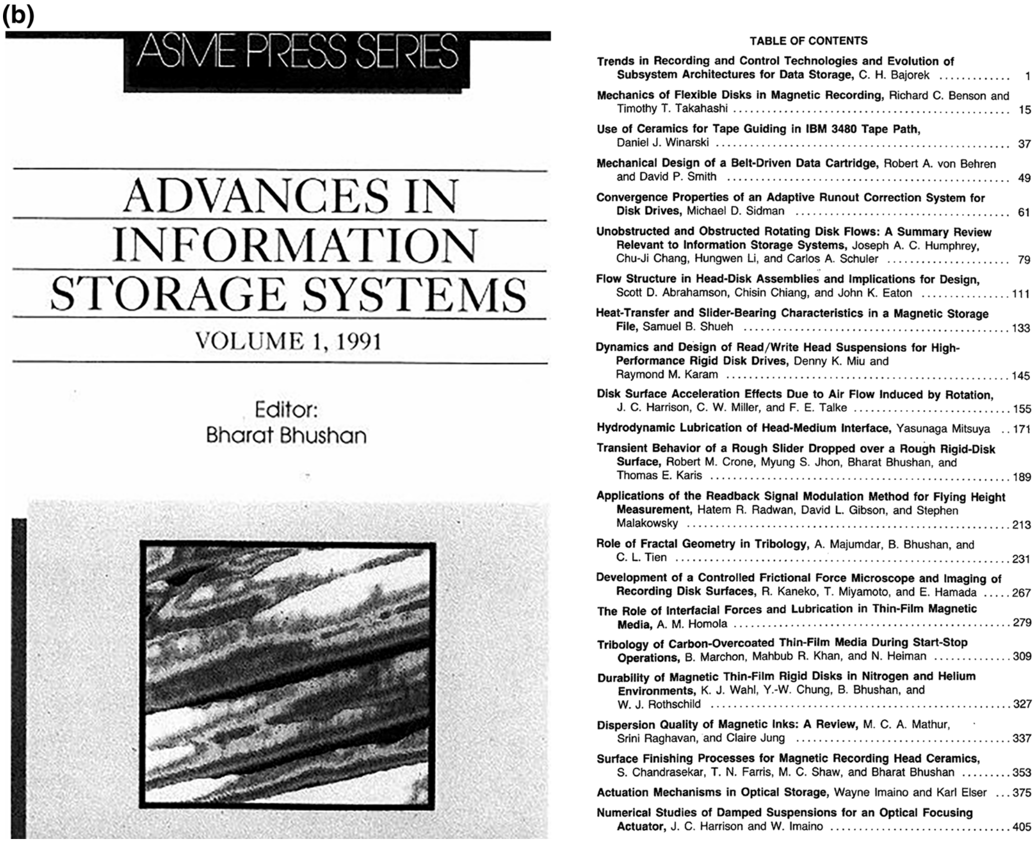
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Fig. 10 Title page and table of contents of the proceeding of the **a** first Symposium on Tribology and Mechanics of Magnetic Storage Systems (1984), and **b** the first issue of Advances in Information Storage Systems (AISS) (1991)

(a)

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Mission Statement

JISPS, Journal of Information Storage and Processing Systems is an international journal whose aim is the advancement and dissemination of information describing the newest technological developments and discoveries concerning information storage and processing systems. Its intention is to educate and promote original research and brief reviews in the field of information. Articles for submission in the following areas is encouraged:

- Information and its meaning
- Advances in technique
- Interactions between information storage and processing systems

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(b)

Microsystem Technologies

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Micro- and Nanosystems

Information Storage and Processing Systems

Editors-in-chief
H. Reichl
B. Bhushan

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(continuation on cover page IV)

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Sensors, Actuators, MEMS

Micromechatronic

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Fig. 11 Title page and table of contents of the **a** first issue of Journal of Information Storage and Processing Systems (JISPS) (1999), and **b** first issue of Microsystem Technologies (MST) after its expanded scope (2002)

computers, the demand for the data storage drives grew. The industry steadily grew and was about USD $50 billion annually in early 2000s with hard disk drives commanding more that 90% of the market share. Starting about 2010, magnetic hard disk storage drives have steadily declined for online data storage. In 2018, data processing tape drives remained dominant for archival storage because of high volumetric density (30 TB/cartridge) and low cost in $/MB ($\sim$ $0.02/MB). For completeness, tape drives are also significantly more energy efficient than HDD. Tape drive revenues remained steady at about USD $3 billion annually. It is expected that tape drives may remain in use for another two decades, and will outlast HDD. There has been sufficient consolidation leaving few disk and tape drives and media manufacturers.

Related magnetic storage conferences with a focus on tribology and electromechanical, materials science, design and manufacturing issues, first organized in 1984 and 1989, respectively, continue to be held annually and the research papers are published in a dedicated journal.

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Dr. Bhushan is an accomplished organizer. He organized the Ist Symposium on Tribology and Mechanics of Magnetic Storage Systems in 1984 and the Ist Int. Symposium on Advances in Information Storage Systems in 1990, both of which are now held annually. He organized two international NATO institutes in Europe. He is the founder of an ASME Information Storage and Processing Systems Division founded in 1992 and served as the founding chair during 1993–1998. His biography has been listed in over two dozen Who's Who books including Who's Who in the World. He has received more than two dozen awards for his contributions to science and technology from professional societies, industry, and U.S. government agencies including Life Achievement Tribology Award and Institution of Chemical Engineers (UK) Global Award. His research was listed as the top ten science stories of 2015. He is also the recipient of various international fellowships including the Alexander von Humboldt Research Prize for Senior Scientists, Max Planck Foundation Research Award for Outstanding Foreign Scientists, and Fulbright Senior Scholar Award. He is a foreign member of the International Academy of Engineering (Russia), Byelorussian Academy of Engineering and Technology and the Academy of Triboengineering of Ukraine, an honorary member of the Society of Tribologists of Belarus and STLE, a fellow of ASME, IEEE, and the New York Academy of Sciences, and a member of ASEE, Sigma Xi and Tau Beta Pi.

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